MMSE Equalization for OFDM Systems over Frequency-Selective Fading Channels

M. Janani Priya[1], R. A. Priya[2]
[1,2]Assistant Professor, Department of EEE, Saveetha School of Engineering, Chennai, India

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Abstract: Channel estimation is one of the key technologies in Orthogonal Frequency Division Multiplexing (OFDM) systems, which has received more and more consideration. A modified Minimum Mean Square Error (MMSE) is proposed and simulated by MATLAB over a frequency-selective fading channel. Comparing with the conventional MMSE, this algorithm has the advantage of low complexity. Meanwhile, it shows little attenuation of Mean Square Error (MSE) and Bit Error Rate (BER) performances according to the final simulation results, which is promising for practical applications. The orthogonal frequency-division multiplexing access technique has recently been attracting considerable interest especially for wireless local area networks (WLAN's).The use of IFFT/FFT as an efficient way to realize the OFDM function and the concept of the guard interval to avoid the inter symbol interference (ISI) and inter-carrier interference (ICI). This is reflected by the adoption of this technique in applications such as digital audio/video broadcast (DAB/DVB), wireless LAN (802.11a and HiperLAN2), broadband wireless (802.16) and xDSL. In parallel, Field Programmable Gate Arrays (FPGAs) are also emerging as a fundamental paradigm in the implementation of these standards. This is due to their increased capabilities (speed and resources).

Keyword: FPGA, WLAN, OFDM, 802.11a.

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1. Introduction

OFDM can be seen as either a modulation technique or a multiplexing technique. One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or narrowband interference. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers will be affected. Error correction coding can then be used to correct for the few erroneous subcarriers. OFDM technology is a popular technique for transmission of signals over wireless channels, due to its many advantages such as the high spectral efficiency, robustness to frequency selective fading, and the feasibility of low-cost transceiver implementations [1].

For wideband wireless communication, it is necessary to dynamically estimate the channel before demodulating the signals. There are two kind methods for channel estimation. The first is the pilot assisted estimation, the pilot signals are embedded in certain sub-carriers of each OFDM symbol. At the receiver, the channel components estimated using these pilots are interpolated for estimating the complete channel. Based on the criterion of realization, it can be classified as Least Square (LS)[2], MMSE[3]-[4], maximum likelihood estimator[5] and so on. The second category is the blind channel estimation[6]. The blind schemes avoid the use of pilots, for achieving high spectral sufficiency. This is achieved at the cost of higher implementation complexity and some amount of performance loss.In this paper, we propose a low complexity MMSE estimation scheme which can reduce computational complexity but cause little attenuation of performance. The final scheme shows to be efficient according to our extensive computer simulations.

Wireless communications standards and digital subscriber lines technology, in addition to other communication technologies, are utilizing the widely adopted Orthogonal Frequency Division Multiplex (OFDM) technique. This is due to the genuine advantage of OFDM over single carrier system in multi-path fading channels. Among the standards that are based on OFDM are the IEEE 802.11a&g for Wireless Local Area Networks (WLANs), Wi-Fi, and the growing IEEE802.16 for Metropolitan Access, Worldwide Interoperability for Microwave Access (WiMAX). The fast growth of these standards has paved the way for OFDM to be among the widely adopted standards and to be as a fundamental candidate for the construction of the next generation telecommunication networks.

OFDM is of great interest by researchers and research laboratories all over the world. It has already been accepted for the new wireless local area network standards IEEE 802.11a, High Performance LAN type 2 (HIPERLAN/2) and Mobile

Multimedia Access Communication (MMAC) Systems. Also, it is expected to be used for wireless broadband multimedia communications. Data rate is really what broadband is about. The new standards specify bit rates of up to 54 Mbps. Such high rate imposes large bandwidth, thus pushing carriers for values higher than UHF band. For instance, IEEE802.11a has frequencies allocated in the 5- and 17- GHz bands.

2. System Model and Channel Model

The frame structure of a OFDM system signal frame consists of two parts, a frame head and a frame body as well. The L_{PN} -length frame head, serving as TGI, is composed of a pre-amble, a PN sequence and a post-amble. The frame head PN(n) is a series of complex-valued symbols with QPSK constellation of which the real and imaginary parts are identical. The PN sequence with L_m samples is generated based on m-sequence, and the pre-/post-amble is the cyclical extensions of the PN and has the length of L_{pre} and L_{post}, respectively. OFDM modulation is applied to the frame body, i.e. the N_c -length inverse discrete Fourier transformation (IDFT) block.

A base-band OFDM system is shown in Fig.1 without forward-error-coding (FEC) part. At the transmitter side, the random bit stream is mapped to complex-valued symbols, and each block bearing N_c data symbols is modulated by means of IDFT (implemented by IFFT—inverse fast FT) to generate a frame body. The PN head (namely frame head) is inserted in the start of each frame body to construct a signal frame, and the symbol rate of both parts is 1/T=7.56 MSPS. The transmitted signal s(t) is generated by an SRRC (squared root raised cosine) filter. Meanwhile in the receiver, the received signal r(t), interfered by multi-path channel and CFO, is 4-fold over-sampled with a certain SFO. The nominal sampling period T_s=T/4. Then the SFO and CFO of the received signal are corrected in the synchronizer
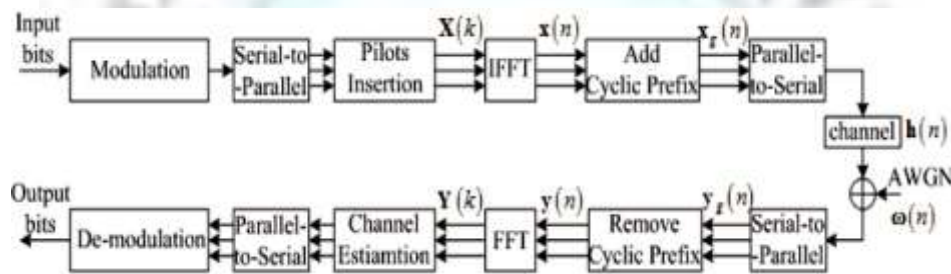

Fig 1: Block diagram of a base-band OFDM system

SFR & CFR. The PN head is removed from the filtered signal, which needs the help of frame timing and of the estimated channel impulse response (CIR). From the separated frame body, data symbols are demodulated by DFT (implemented by FFT—fast FT). The channel equalizer eliminates channel distortions, and then the de-mapper transforms the equalized symbols into the output bits. For reducing spectral overhead on pilot, time-domain synchronous OFDM replaces cyclic prefix (CP) with pseudo-noise (PN) sequence and removes pilot from OFDM signal. Thanks to its higher channel throughout, OFDM has been adopted as one of the key modulation schemes for Chinese standard of digital terrestrial television broadcasting (DTTB).

The digital baseband receiver, one of the key parts in an OFDM system, plays an important role in determining the overall transmission performance. Design and implementation of the OFDM receiver have been topics of intense activity for researchers and engineers since OFDM was invented. Numerous papers have been published to address issues concerning OFDM receiver design, including the issue of synchronization for received signals. An OFDM system is very vulnerable to synchronization errors and there are more stringent requirements for synchronization tasks in an OFDM receiver than in others. In addition to the initial estimation for synchronization parameters, further elimination of residual synchronization errors (including carrier-frequency and timing errors or offsets) is absolutely necessary. The absence of an efficient error elimination scheme in the OFDM receiver would severely degrade the overall system performance. Obviously, how to design an efficient and robust elimination scheme for residual synchronization errors is a critical issue while implementing a digital OFDM receiver.

Error elimination is mainly composed of two processing tasks, error estimation and error correction. Various algorithms have been proposed to estimate both the carrier frequency offset (CFO) and the sampling time offset (STO) using phases or phase differences of signals at pilot subcarriers. Underlying these algorithms is the least-squares (LS) line-fitting method or its weighted version. In order to obtain good estimation accuracy, the number of pilot subcarriers per OFDM symbol should

be large enough; otherwise, for many burst-type OFDM systems (such as IEEE 802.11a/g WLANs and 802.16d/e BWA systems), due to very limited number of pilot subcarriers per OFDM symbol, phase differences have to be averaged over many OFDM symbols for the sake of noise suppression. However, averaging across many symbols calls for large data storage and slows down the estimator's response to diminishing residual errors. Next in the chain comes the IFFT block. This block was the only main block not designed in VHDL by the author, the Intellectual Property (IP) core available in the Xilinx development environment (ISE) was utilized [7]. The generated IP was implemented to run in a pipelining streaming I/O mode for continuous processing of the arriving data instead of working on the whole symbol samples all at once. This capability came from the pipelining provided by the previous and the next stages, where each generated I/Q pair in the I/Q bank is fed to the IFFT processor. Next, after the required number of cycles by the IFFT block, the generated real and imaginary pairs are forwarded to the CP block.

To avoid inter-symbol interference and to maintain the orthogonality of the OFDM signal, the last L samples in a frame are duplicated at the start of the frame. This technique is used in most OFDM systems and is referred to as adding a cyclic prefix. The synchronization algorithm uses the correlation between these identical data blocks to estimate the time and frequency offset. To maintain reliable communication, the system needs to be synchronized both in time and in frequency. In this paper, we refer to time synchronization as finding the frame start of an OFDM block. Synchronizing the phase of the sample clock is not necessary, and sample-clock synchronization will therefore not be considered in this paper. The requirements for the time offset estimation depend on the length of the CP and the length of the channel impulse response. If the FFT window is positioned in the part of the cyclic prefix which is not affected by the previous symbol due to channel dispersion, the only effect of the output symbols from the FFT will be a phase shift proportional to the time offset. The difference in phase shift between two consecutive subcarriers will however be constant for all subcarriers. Since this difference is constant for all subcarriers, and our data is differentially modulated, we can estimate the phase offset and compensate for it before the data is demodulated. By this technique, a small time offset will not yield any significant performance degradation.

3. Simulation Results and Computational Complexity

In this section, MSE and BER performance of channel estimation methods mentioned in this Section are investigated by MATLAB simulations. The modulation and demodulation method of pilot symbols and data symbols is QPSK. The basic system parameters for the simulations are summarized in Table I. The frequency selective fading channel parameters can be generated by typical metropolis channel model.
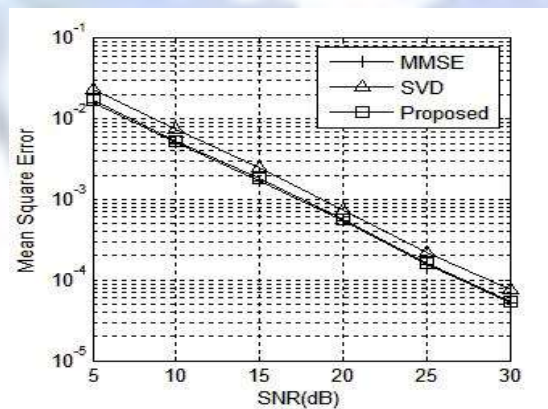

Fig 2: MSE vs. SNR of three channel estimation methods

Fig.3 shows the MSE performance behavior of three channel estimation schemes in frequency-selective fading channels. From it we can see that the proposed method outperforms LS significantly. There is a performance improvement of around 2dB. Meanwhile the proposed method exhibits almost the same performance as MMSE, using the theory of diagonal matrix to reduce the computational complexity will not lead to attenuation of performance. The average bit error rate performance of three channel estimation schemes for QPSK is shown in fig 3. It can be seen from this fig. that the proposed method is close to that of MMSE estimator, while it outperforms the LS estimator is about 5dB for the bit error rate of 2x10-2.
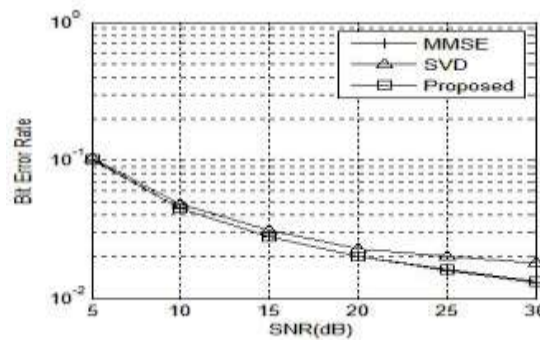
Fig 3: BER vs. SNR of three channel estimation methods

Table: Computational Complexity of the Proposed MMSE and the Conventional Scheme When N=128

	Conventional	Proposed	CCRR
multiplications	81,920	33,408	59.21%
additions	16,384	128	99.22%

In diagonal matrix multiplication operations and two diagonal matrix inversion operations, which requires $2N^2 + 5N$ multiplications and N additions. When N=128, the CCRR of the proposed MMSE over the conventional scheme is given in Table III.From Table III, we can draw a conclusion that the computation complexity of proposed MMSE is much lower than the conventional scheme, which shows the superiority of our scheme.

4. Conclusion

In this paper, a novel MMSE channel estimation scheme is proposed and its performance is numerically confirmed for the OFDM system proposed in the IEEE 802.16 standard. The results show that as compared with conventional MMSE, using this scheme can reduce the computational burden and suffer little attenuation of performances. Therefore, it is rather attractive for practical application in OFDM-based communication systems. An OFDM synchronization unit is presented. The algorithm is computationally intensive, but by making proper simplifications, it is shown that a hardware implementation is feasible. Several optimizations to reduce the complexity have been designed. Because of overlapping multicarrier modulation technique it save almost 50% of bandwidth and also reduce crosstalk between subcarriers.

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